

LARGE-SCALE MULTIWAVELENGTH CAMPAIGNS FOR BLAZARS IN THE GLAST ERA

STEFAN J. WAGNER

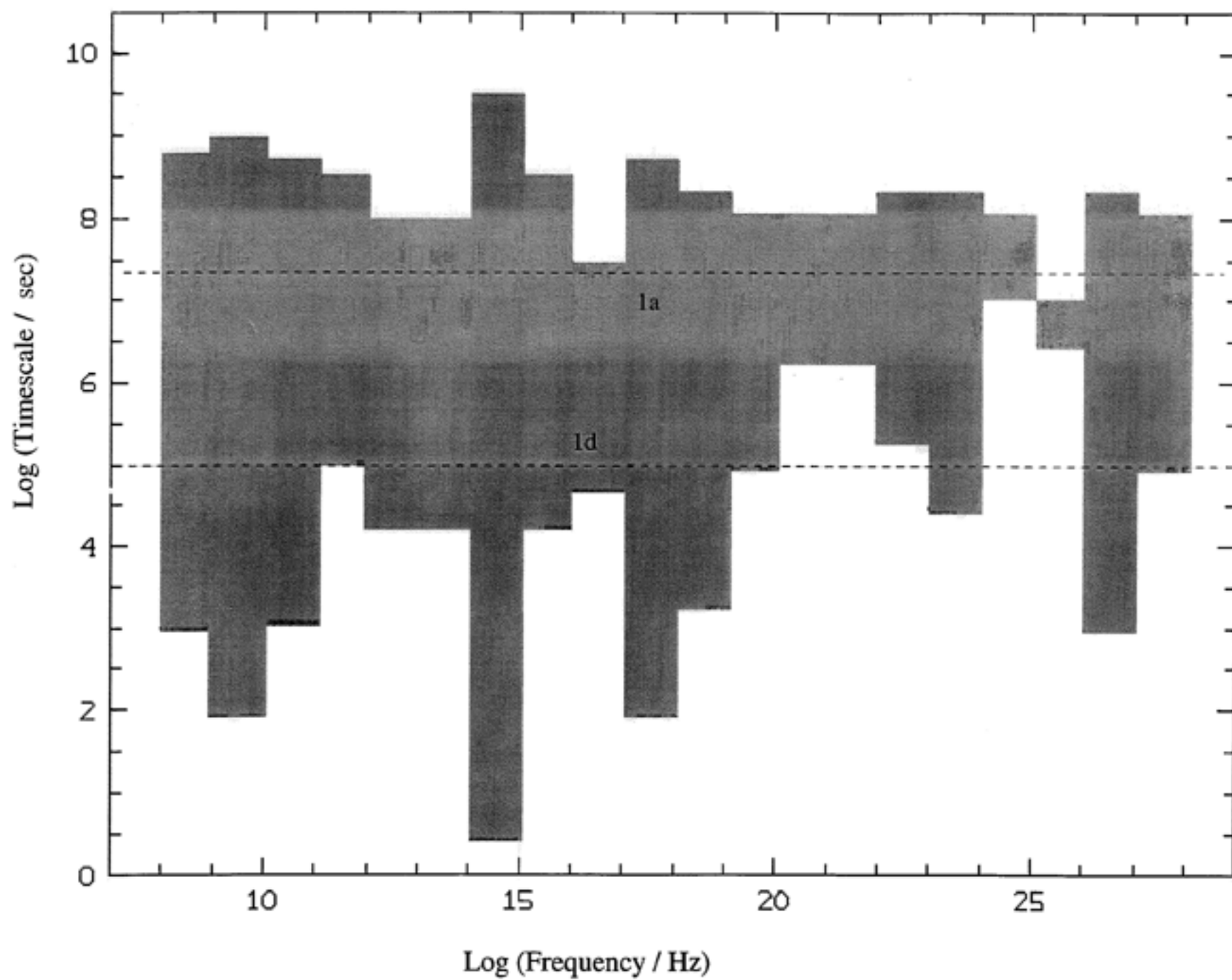
LSW Heidelberg, Germany

- Issues:**
- * **fluxes \rightarrow SED (long-term)**
 - * **are γ rays correlated to other bands?**
 all sources?, always?, all time-scales?
 - * **lags \rightarrow reprocessing (dense sampling)**
 - * **polarization, emission lines, VLBI structure**
 - * **early IDs of new γ sources**
 - * **confirm IDs (confusion, catalogs)**

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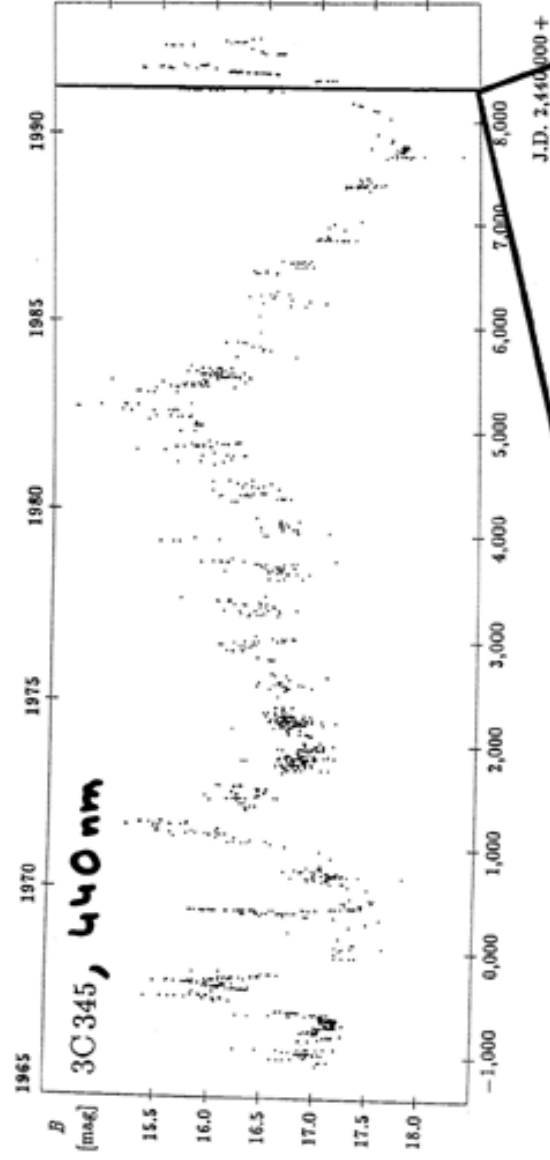
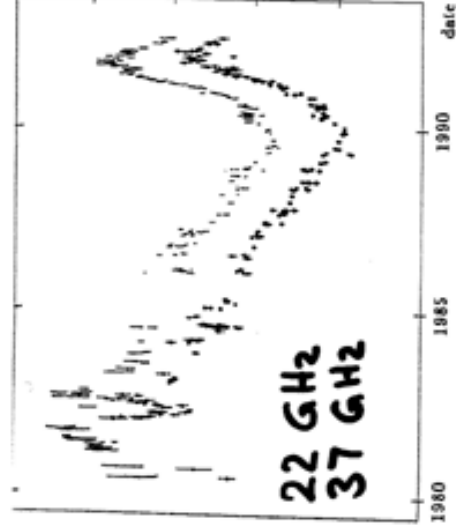
- Relevant time scales
- Measurements of interest
- State of the art
Technical constraints
- What is done routinely now ?
What could be done routinely ?

... in the different frequency regimes

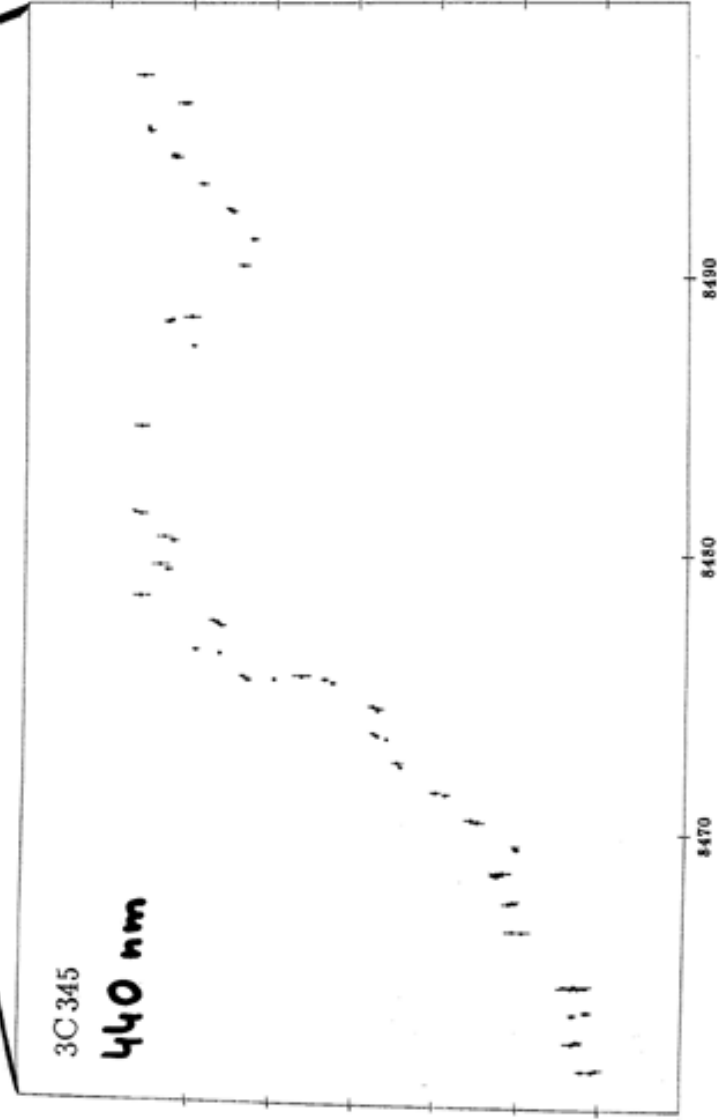


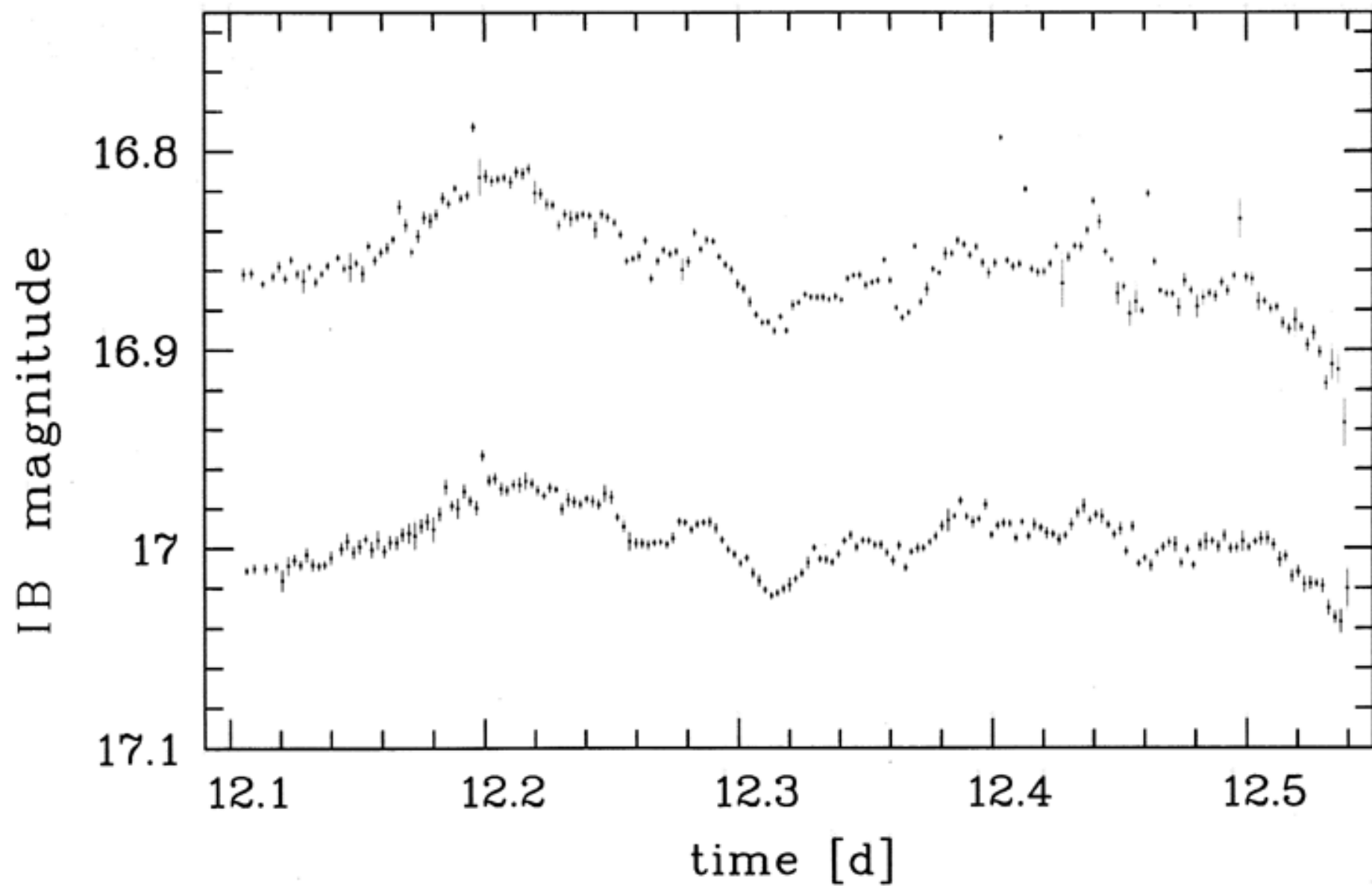
Schramm et al., 1993
Wagner et al., 1994

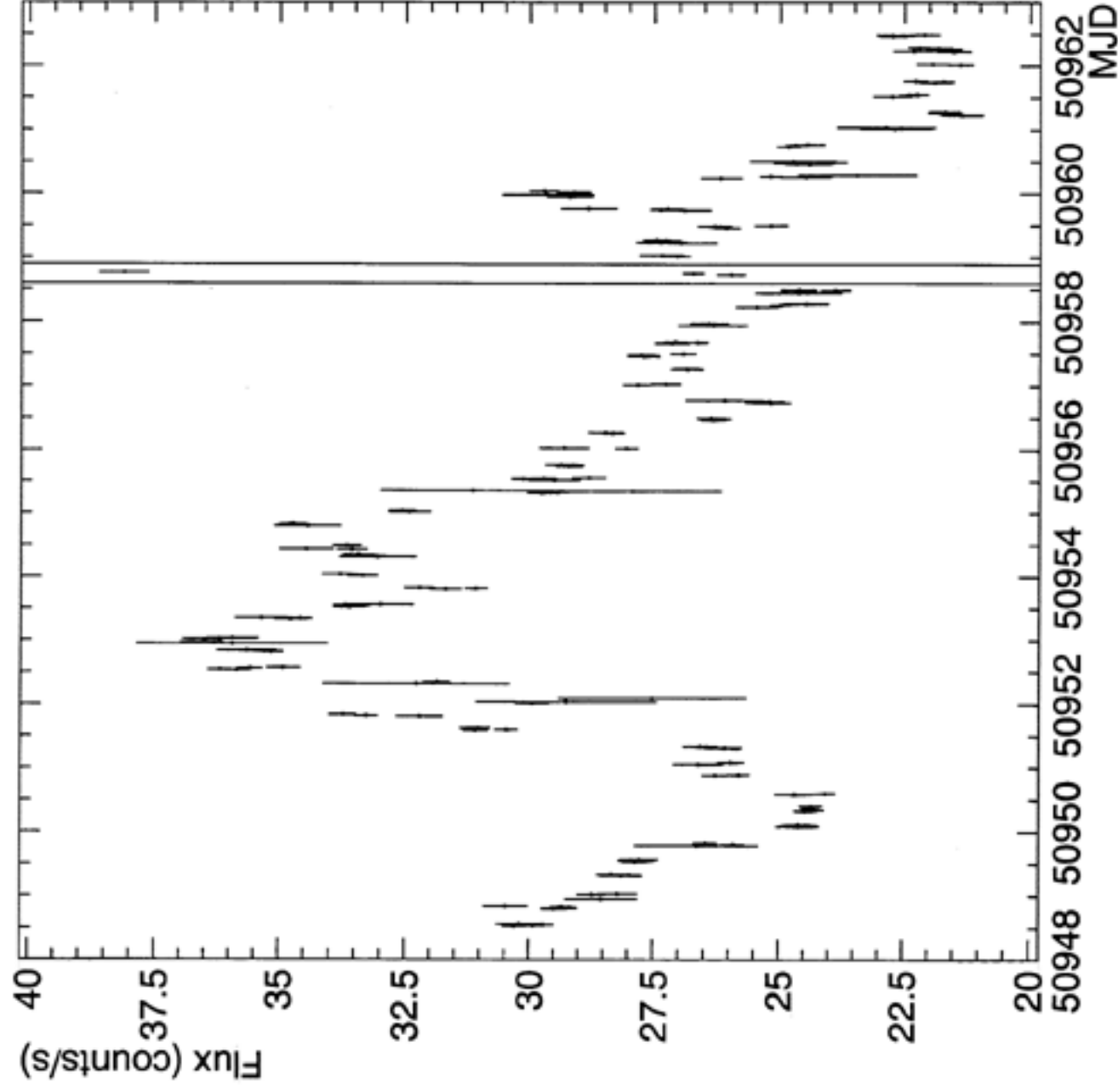
DECADES



DAYS







LARGE-SCALE MULTIWAVELENGTH CAMPAIGNS FOR BLAZARS IN THE GLAST ERA

TOO

Rita Sambruna

$\Delta T \Rightarrow$

Dedicated Campaigns

$\Delta T \sim 1$ month

pre-defined epoch \rightarrow RA \rightarrow pre-defined sources

dedicated telescopes

coordinated, small facilities

\Downarrow N

Continuous Monitoring

$\Delta T \sim$ GLAST life-time

all GLAST sources

dedicated telescopes, ASMs

Radio/mm (1 - 250 GHz)

- Flux density
- Polarization
- Spectral indices
- (VLBI) structure

Near-IR/Optical (2300 - 300 nm)

- Flux density
- Polarization
- Spectral indices
- thermal emission (lines)

X-rays (0.1 - 100 keV)

Greg Madejski

- Flux density
- Spectral indices

VHE (0.1 - 50 TeV)

Henric Krawczynski

- Flux density
- Spectral indices

Radio/mm (1 - 250 GHz)

Sampling, visibility, and weather

$\Delta T < 1$ day not routinely necessary.

Visibility only limited by latitude (75 % of sky) and sun (~ 45 deg).

Sensitivity to weather varies from not at all (1 GHz)

to greater than at optical wavelengths (< 30 %).

Telescopes

Dedicated Monitoring Instruments:

U Michigan (cm); (NRL-IF); Metsähovi, Finland (mm); ...

(+) reliable (-) single-dish (sensitivity, accuracy), ν -coverage, continuity

For small samples: regular pointing/tau/calibrations

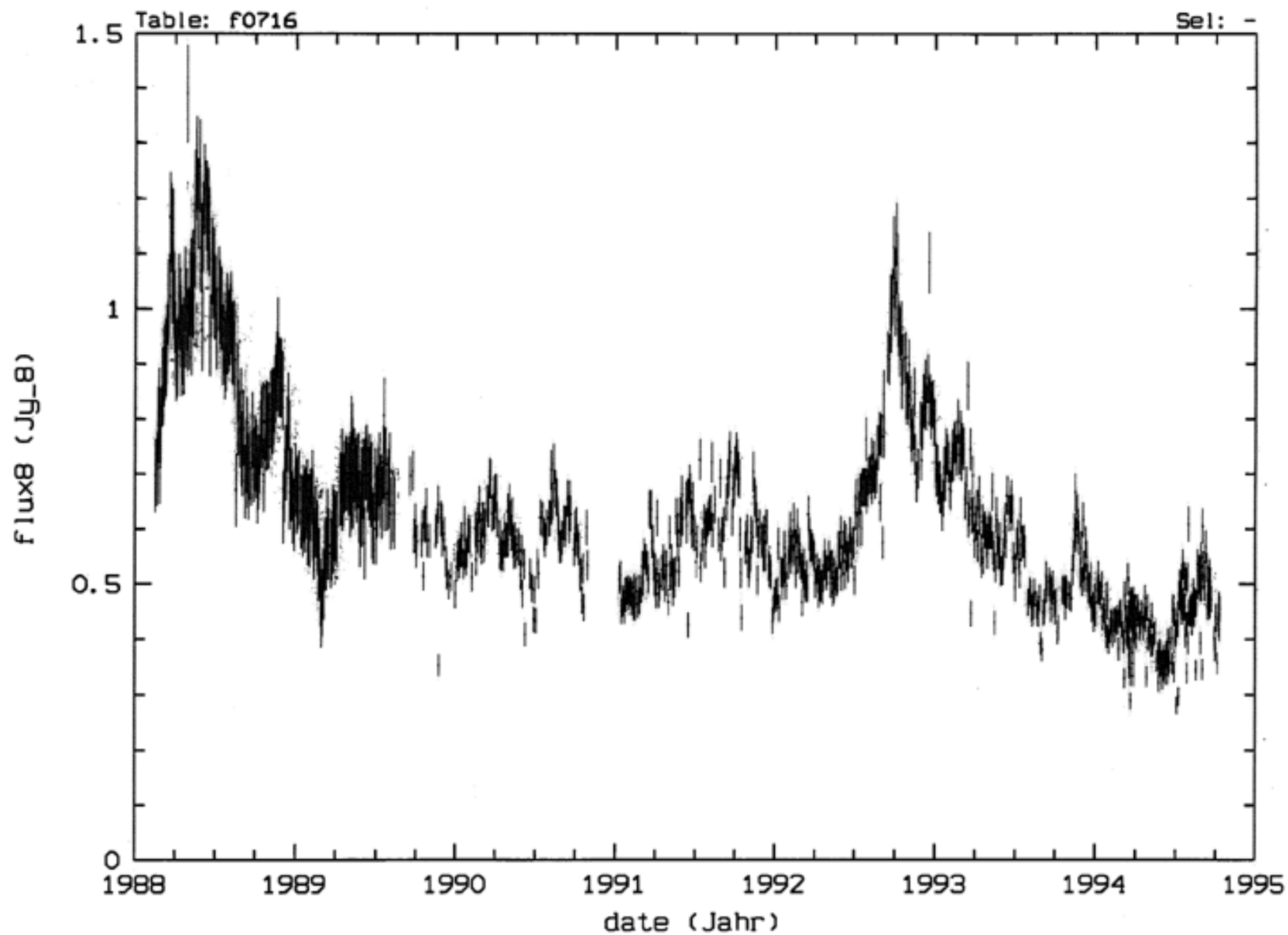
Campaigns: any combination of telescopes, logistics easy

VLBI

Geodetic VLBI (limited dynamic range, low frequency)

Campaigns: no routine operation.

Waltmann



Near-IR/Optical (2300 - 300 nm)

Visibility

- 75 % of the sky visible from a typical site (latitude, elevation constraints)
- 66 % of accessible sky visible during specific campaign (sun constraints)
- 50 % of the sky visible during specific night
- 30 % of the sky visible during specific moment

Weather

- ~ 50 - 70 % clear sky (differential photometry) SEASONAL
- 3 (6) TELESCOPES NEEDED FOR PERMANENT COVERAGE AT ANY MOMENT
- THIS ALSO GIVES 87 % SUCCESS RATE FOR DAILY MONITORING

Instruments and measurements

- 1 % error on 19th mag source ~ detection of 24th mag source.
- 50" (1.2m) telescopes for photometry
- 100" (2.4m) telescopes for polarimetry/spectroscopy

LARGE-SCALE MULTIWAVELENGTH CAMPAIGNS FOR BLAZARS IN THE GLAST ERA

X-rays (0.1 - 100 keV)

Greg Madejski

Dedicated Instruments

Chandra, XMM-Newton, Astro-E, ... (< 1 week)

All Sky Monitors

MAXI, Lobster, Rosita, ...

VHE (0.1 - 50 TeV)

Henric Krawczynski

Constraints

As in optical **plus** moon constraints

50 %, predictable (+), window (-)

Telescopes/Arrays

VERITAS

MAGIC

HESS

CANGAROO

Near-IR/Optical (2300 - 300 nm)

dedicated instruments

best solution (in automatic operation):

robotic telescopes work!

proposal for dedication of 1.2m telescope to GLAST in Germany

dedicated networks

are (have been) operational at present (in the past):

e.g. WEBT (Mattox, Villata, Wagner, ...), OJ-94 (Sillanpää et al.)

coordinated campaigns

have been operational in the past (e.g. 3C 279 (Hartman et al.))

Problems/Concerns:

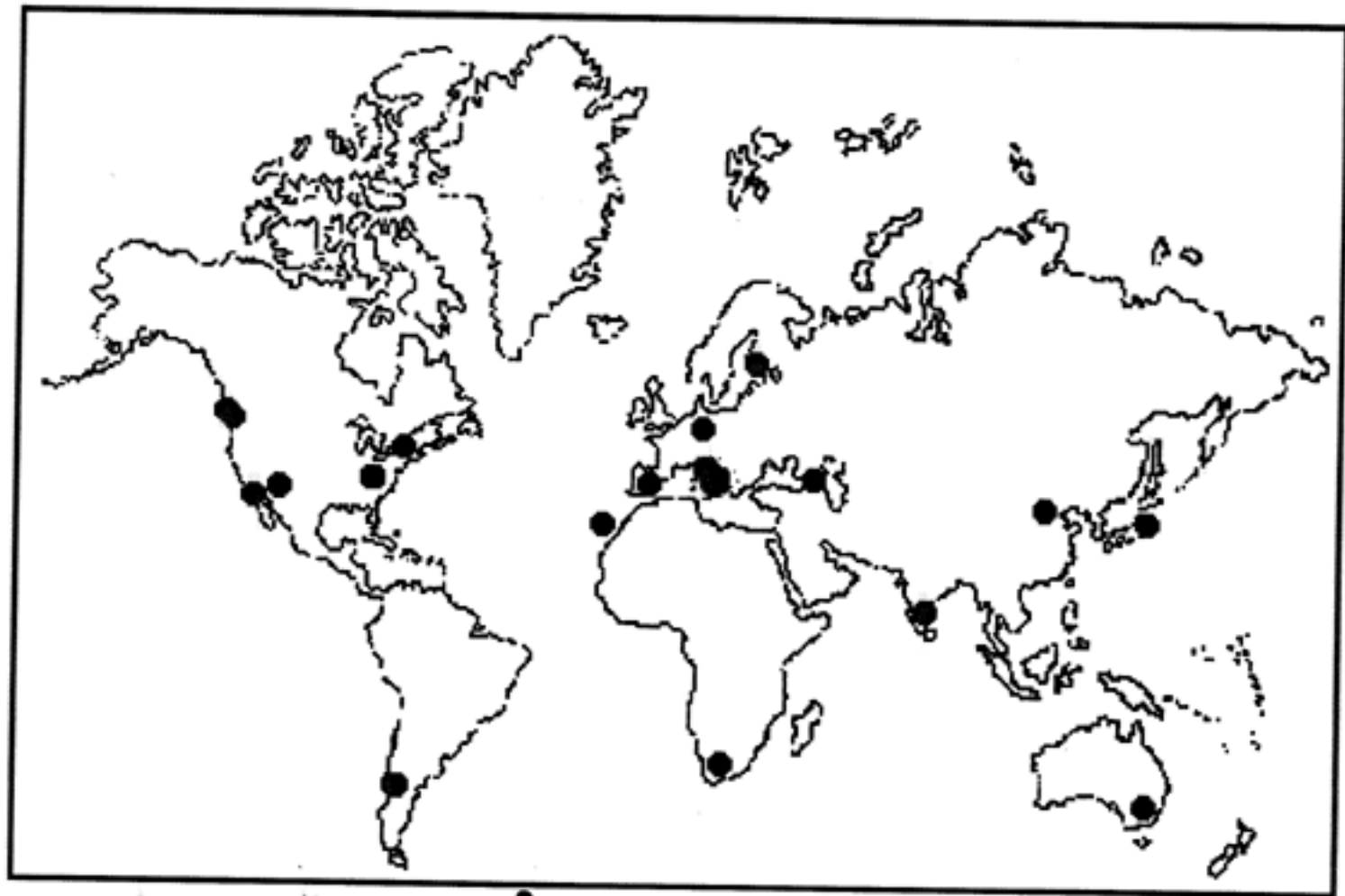
Current operation involves large amounts of manpower/'result'.

Motivation in routine operation (long-term, many campaigns).

Coordination (observers, times, sources).

Homogeneity and data quality.

Whole Earth Blazar Telescope (WEBT)



<http://astro.fmarion.edu/webt>

The Importance of Multiwavelength Observations for GLAST

OR

The Importance of GLAST for Multiwavelength Observations

GLAST Blazar Workshop

2001/04/02

I. Introduction

Although this workshop is nominally about blazars, this title I was given doesn't specifically say "blazars", so I will allow myself to be sidetracked onto a couple of other topics for which multiwavelength observations are relevant.

Despite the 14 decades difference in frequency, radio emission is a better predictor of GeV gamma-ray emission than is X-ray emission. EGRET detected over 60 radio-loud blazars, but only two or three X-ray loud blazars. In addition, EGRET has detected six radio pulsars, but only one or two X-ray pulsars.

The conclusion we reach from this is that GeV gamma rays are associated with high-energy electrons and positrons, which produce synchrotron radiation in both blazars and pulsars. The gamma rays are almost certainly not synchrotron radiation. In the pulsars, they are probably curvature radiation, which is closely related to synchrotron radiation, but

in blazars it is likely that gamma rays arise from the inverse-Compton process.

X-rays, on the other hand, are usually most prominent when produced as thermal emission from hot plasmas, which are seldom (if ever) hot enough to produce GeV gamma rays.

Of course, high-energy gamma rays are also produced by high-energy nucleons; indeed, the diffuse Galactic plane emission, which dominates the high-energy gamma-ray sky, is largely from interactions of cosmic-ray nucleons with interstellar gas. So far, however, there is no conclusive evidence for gamma-ray emission from discrete objects due to hadronic cosmic rays, but there is circumstantial evidence linking supernova remnants with some of the EGRET unidentified sources. We can't forget about the nucleons when we discuss the gamma-ray emission from blazars; the nucleons haven't gotten a lot of attention, and they entail significant problems, but they are also possible contributors to the gamma-ray emission.

Most theories attempting to explain the origin of the gamma rays from blazars place that source much closer to the central engine (the supermassive black hole) than the source of the synchrotron radiation. While the gamma rays are believed to come from near where the electrons and positrons are accelerated; the radio emission is usually thought to come from much farther away.

II. But what about all the frequencies and wavelengths between radio and gamma rays?

The reason I have ignored them so far is not because they are unimportant, but because they are relatively more important in most other astronomical objects (e.g., normal stars, X-ray binaries, Seyfert galaxies, even radio-quiet quasars). Those objects that are bright only in IR, optical, UV, and X-rays are much more numerous than the pulsars and blazars; thus the pulsars and blazars are most prominent in radio and gamma- rays.

The intermediate frequency bands are also important in the pulsars and blazars, as illustrated in the following two spectral energy distributions (SED's). They show the energy received per logarithmic bandwidth.

Pulsar figure - These are the pulsars detected by the instruments on CGRO. The thing to note here is that, with the exception of Geminga, all of these were first discovered as radio pulsars. This is despite the fact that the radio is a minor component of the energy budget of these objects. The energy output is dominated by the gamma-rays. The X-rays are significant for most, but the optical emission is energetically significant only for the Crab pulsar, the youngest of the lot.

Blazar figure - This shows SED's for a variety of blazars, both OVV quasars (with stronger optical lines) and BL Lac objects (with weak or absent lines). Although the energy distribution has an important or even

dominant component in the gamma-rays, here we see a strong contribution also in the IR to optical. Note that despite the small energy contribution from the radio, most of these objects were discovered in radio, and are described as radio-loud. The radio-*quiet* AGN's show an even steeper roll-off down to the radio!

These two figures address my subtitle, "The Importance of GLAST for Multiwavelength Observations". Obviously, if you ignore the GeV gamma rays, you miss a major portion, sometimes the dominant part, of the energy received from the blazars.

The answer to the original title, "The Importance of Multiwavelength Observations for GLAST", is more complex, so I will try to sneak up on it gradually.

III. So why is this workshop only about blazars? The pulsars are an important source class too!

The reason is that blazars are more complicated, in particular with regard to time variations. In all bands for which investigations have been possible, rotation-powered, or radio, pulsars are remarkably stable in their total flux, when averaged over a number of periods. The Crab pulsar has been used as a "standard candle" for over 25 years in gamma-ray astronomy, and even longer in X-rays.

Blazars, however, are anything but standard candles. Indeed, large and rapid variations are part of the definition of the two subclasses that were first grouped together as blazars, the BL Lac objects and the optically violently variable (OVV) quasars. In some of these objects the fluxes can vary by a factor of 100, at least in the optical and gammas, and the variation timescale for a factor of two change can be less than one hour.

Back to the pulsars for a moment: Although they emit over a very broad range of frequencies, it seems possible to identify the emission in at least some bands with different physical locations. Thus the gamma-rays are likely coming from the region between the neutron star and the speed-of-light cylinder. The soft X-rays, in the pulsars where they are detectable, are probably thermal emission from the surface of the neutron star polar regions. And the radio emission probably arises from coherent processes above, but very near, the magnetic poles.

In the blazars, however, the regions that produce the gamma-ray, X-ray, and optical emissions seem to be more closely related, contiguous, or overlapping, or maybe even identical. Because of constraints due to synchrotron self-absorption, the radio emission must be generated at a significant distance from the central black hole. It is widely believed that the higher-frequency emissions originate much closer to the black hole, although there are scenarios that are claimed to be able to generate the optical through gamma-ray emission farther out.

In order to understand these closely related emissions in widely spaced bands, it is useful to examine correlations between those bands. On timescales of months and longer, the correlations between the fluxes in all bands from radio to gamma rays is very strong. When a blazar is bright in one band, it is very likely to be bright in all of the others. And if it is very dim in one band, other bands are likely to show it dim also. Furthermore, several VLBI radio investigations have indicated that gamma-ray flares are often associated with the emergence of bright knots of radio emission along blazar jets.

The correlation between bands on shorter timescales is not as clear. For some lower-luminosity BL Lac objects, clear correlations have been found between optical, UV, and soft X-ray fluxes, and even between X-rays and TeV gamma rays, on timescales of a day or less. For the higher-luminosity blazars, and also for GeV emission in general, correlations

have been few, and often marginally significant. For the GeV emission, this is due in part to the fact that blazars are seldom bright enough to be detectable by EGRET within one day. One notable exception was the large GeV gamma-ray flare of 3C 279 in 1996 Feb, which correlated well with X-ray fluxes detected by RXTE. There was no discernible time offset, as shown in Figure 3. Unfortunately, optical coverage during that time was sparse and inconclusive.

In early 1999, and also in early 2000, 3C 279 was again bright in optical, X-rays, and GeV gammas. The resulting Targets of Opportunity with RXTE and CGRO were accompanied by unprecedented optical coverage. The light curves from those two campaigns are shown in Figures 4 and 5. Considerable variation is obvious in all three bands in both 1999 and 2000, so it is reasonable to hope that significant correlations might be found. Examinations of the light curves by eye suggests several possible correlations, such as an optical/gamma correlation in 1999, with a gamma lag of ~ 2.5 days, and a gamma/X-ray correlation in 2000 with no delay. But there is no obvious case where all three bands correlate. Formal correlation analysis using the discrete correlation function does indeed yield some evidence for the two correlations just mentioned, and possibly some others, but again, little evidence for any correlation that encompasses all three bands.

It is possible that correlations in the higher-luminosity blazars just aren't as clean as those in the low-luminosity BL Lacs. There is mounting evidence that the low-luminosity BL Lacs are simpler objects. In those objects, the inverse Compton luminosity never seems to exceed the synchrotron luminosity, even in large flares; this is to be expected for the synchrotron-self-Compton process. In the higher-luminosity blazars, the Compton luminosity can exceed that from synchrotron radiation by more than an order of magnitude. The SED's of the low-luminosity BL Lacs seem to be well described by reasonable synchrotron-self-Compton models, whereas the higher-luminosity blazars require extreme assumptions in synchrotron-self-Compton models. They are much more easily accommodated as Comptonization of external soft photons, possibly with a small but significant contribution from synchrotron-self-Compton.

IV. But we will never know the full answer on GeV correlations in the more luminous blazars unless we get better light curves. I concentrate again on the optical, X-rays, and GeV gammas, because such bands as submm, FIR, and EUV, although potentially quite useful, are so difficult to observe and/or so oversubscribed that it seems hopeless to expect densely sampled light curves. For the GeV gammas, the X-rays, and the optical, there is both good new and bad news. Good news first:

In the optical and GeV bands, the improvements are on the way. Clearly, GLAST will provide gamma-ray observations of improved statistical accuracy, which is crucial, but also longer periods of observation on many objects. Less familiar to the gamma-ray observers, but of comparable importance for the correlations I mentioned before, is the revolution that is going on in the automation of small optical telescopes. A world-wide network of such automated systems could provide optical light curves on sub-day timescales to compare with those from GLAST.

In X-rays the situation is less encouraging. It seems unlikely that RXTE will still be operating by the time GLAST is launched. The big new X-ray telescopes Chandra and Newton, although extremely powerful, are not as flexible as is RXTE, and are unlikely to provide monitoring of the type needed for correlation with the gamma rays. There has been discussion, and even some planning, for a super-XTE follow-on; however, it seems unlikely that it will be available when GLAST is launched. The gamma-

ray burst mission Swift will have X ray monitoring capability, but that is not its primary goal, so the availability is not clear. I believe Greg Madejski will address this topic in more detail later.

V. Finally, I mention another topic on which multiwavelength observations including GLAST should have a significant impact. The largest class of EGRET sources is those that are unidentified. They occur over the entire sky, but are most heavily concentrated near the Galactic plane. Identification of those Galactic plane sources with objects known at other frequencies will be a difficult task even with GLAST, because of the multitude of objects present within even the much-smaller GLAST error contours. The unidentified sources near the plane include some that are variable and some that showed no significant variation in the EGRET observations. For those that vary, multiwavelength observations may be crucial in making identifications. An example of this is the highly likely identification recently by Jules Halpern and colleagues of one unidentified EGRET source as a previously unknown blazar near the Galactic plane.

VI. So I have mentioned two ways in which multiwavelength observation will be important to GLAST:

For the blazars, multiwavelength correlations will enhance our ability to understand what is going on in these powerful and complex objects;

And for unidentified gamma-ray sources, multiwavelength observations are a likely tool for making such identifications.